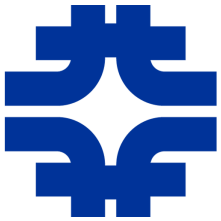
MuCool Test Area Update



Yağmur Torun
Illinois Institute of Technology

All Experimenters' Meeting
Fermilab – July 8, 2013

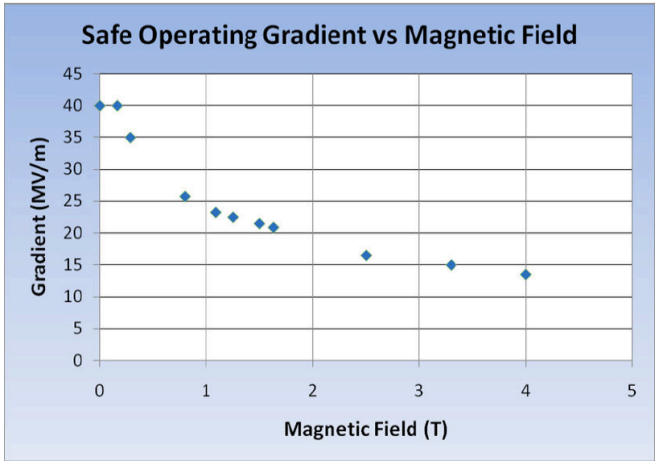
MTA Program Overview

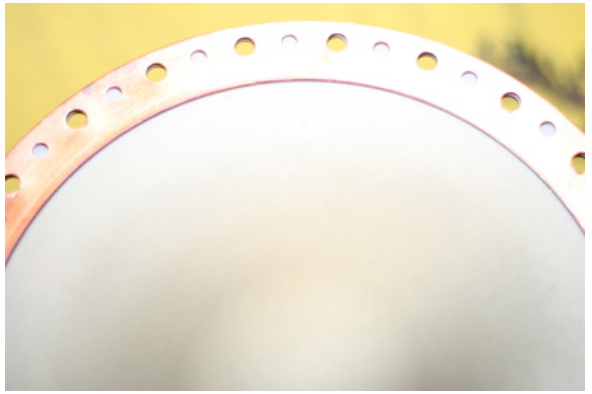
- Goal: Demonstrate a working solution to RF cavity operation in high external magnetic field for muon cooling
- Major MAP deliverable
  - and near-term technical risk for MICE
- Major impact on cooling channel design and future system tests
- A multipronged approach has been followed

⇨ Identify most promising paths for detailed study

805-MHz Pillbox Button Cavity Program (Magnetic Field, Materials, Windows)

- Pillbox geometry with thin curved Be windows
- Button holder for removable electrode inserts
- Used to
  - Quantify magnetic field dependence of gradient
  - Establish feasibility of thin windows (Cu, Be)
  - Test potential cavity materials (Cu, Be, Mo, W)

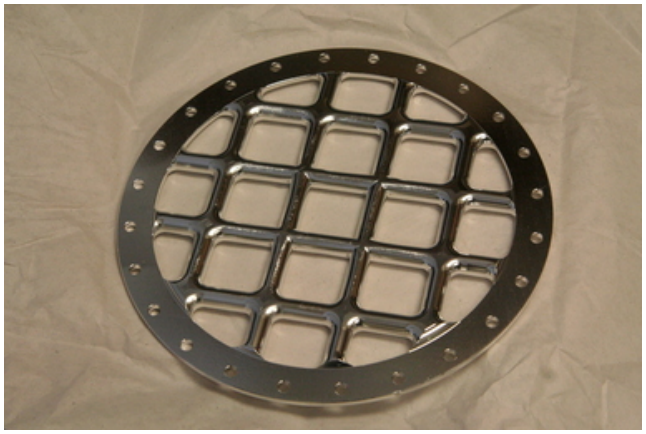


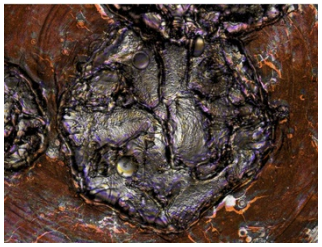


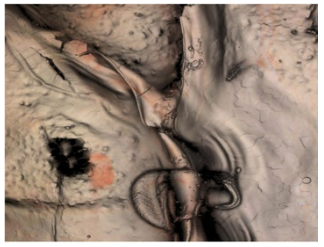
Fermilab 805-MHz Pillbox Button Cavity Program

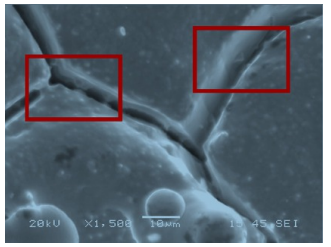
- Most recent test: Be vs Cu buttons & flat Cu endplates
  - Higher gradient with Be buttons
  - Minimal surface damage on Be
  - Surface microscopy complete
- Will also be used to test grid-tube windows

Run	Configuration	B [T]	Gradient [MV/m]
1	flat Cu plates	0	19
2		3	9.5
3	Be buttons	0	27
4		3	29
5		0	40
6		3	31
7		1.5	33
8		3	33
9	Cu buttons	0	30
10		3	28
11		0	35
12		3	28
13		1.5	30



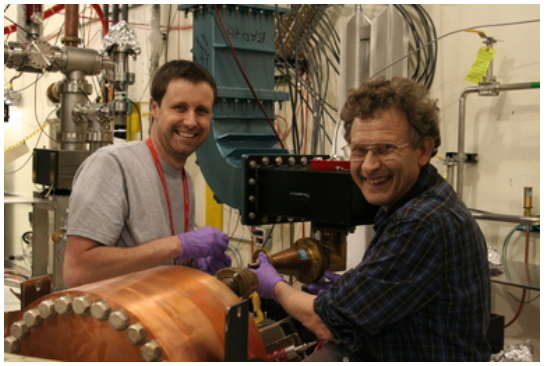


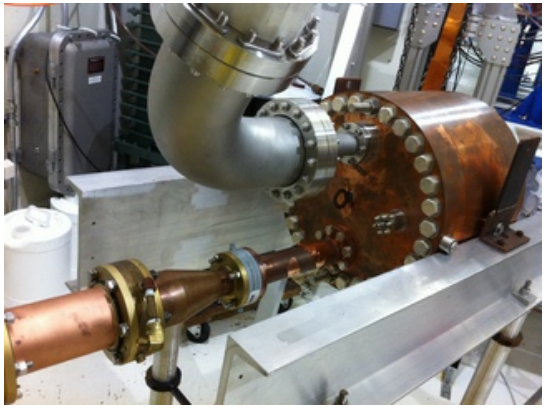


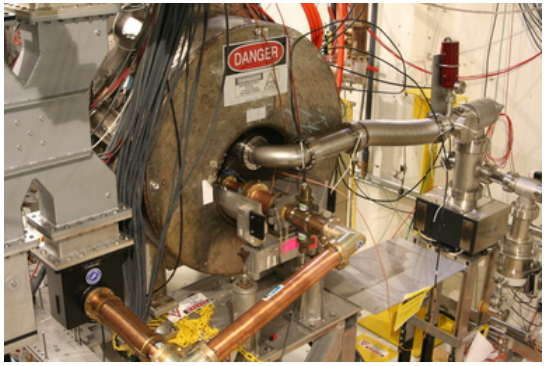


Magnetic Field Dependence
"All-season" Cavity (Muons Inc, LANL)

- Modular pillbox with replaceable endplates
- Designed for both vacuum and high pressure
- Made of 316SS with 25μ Cu plating
- 3.9/6.6/2.7cm-thick center ring/inner/outer plates
- RF volume ϕ29.1 x 12.9 cm
- 1-5/8" coax coupler
- f=810.375 MHz under vacuum, Q=28k
- Power: 1.2MW @ 25 MV/m
- No cooling included in design
- Operated in magnet
  - 25 MV/m at B=0 and 3 T
- Re-run with RF pickup (>3M pulses)
  - Confirmed at B=0 (29 MV/m)
  - 21+ MV/m at B≠0
  - Data analysis in progress

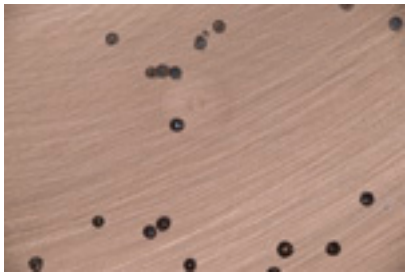


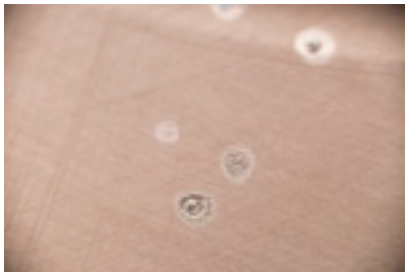


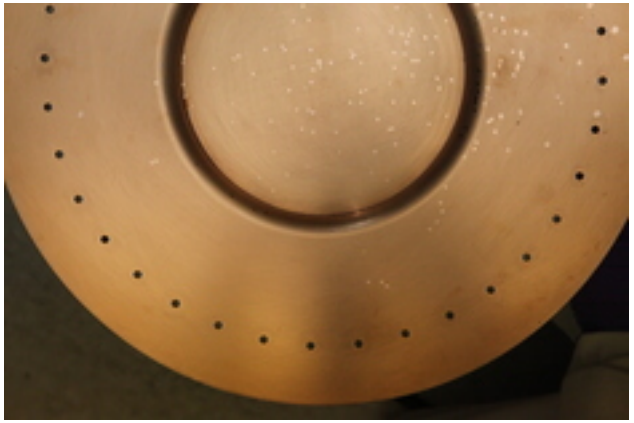


Magnetic Field Dependence
"All-season" Cavity (Muons Inc, LANL)

- Inspection
  - Damage spots on endplates (about same # as sparks)
  - Spot size (mm) similar to those in other Cu cavities
  - Evidence of arcing at coupler center conductor
  - Testing to continue with B up to 5T

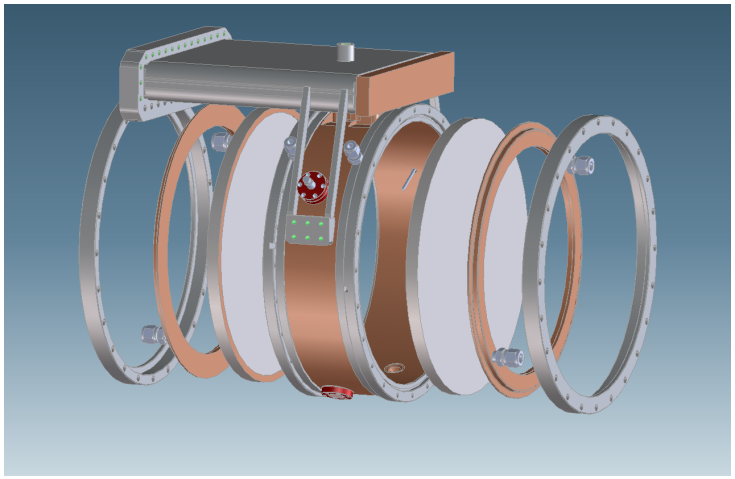


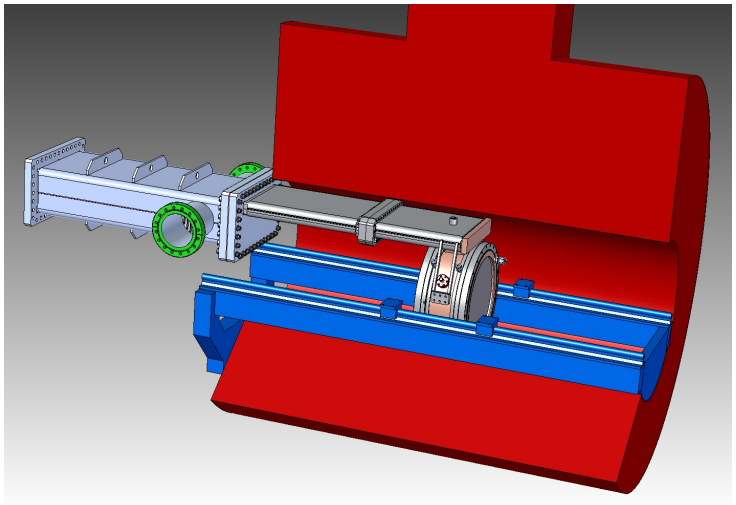




Future Vacuum Pillbox Cavity R&D 805-MHz Modular Cavity (SLAC/LBNL)

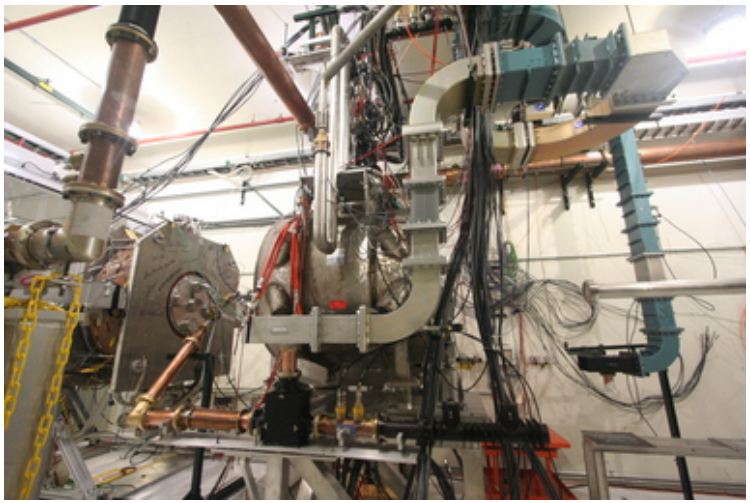
- New R&D vehicle for detailed systematic studies
  - Modular design for easy assembly, parts replacement
  - Removable endplates (Cu, Be, other materials, treated surfaces)
  - Coupling iris moved to center ring and field reduced (*more realistic design*)
  - RF design validated by detailed simulation
  - Ports for instrumentation
  - Fabrication in progress
  - Expected delivery to MTA: Fall `13

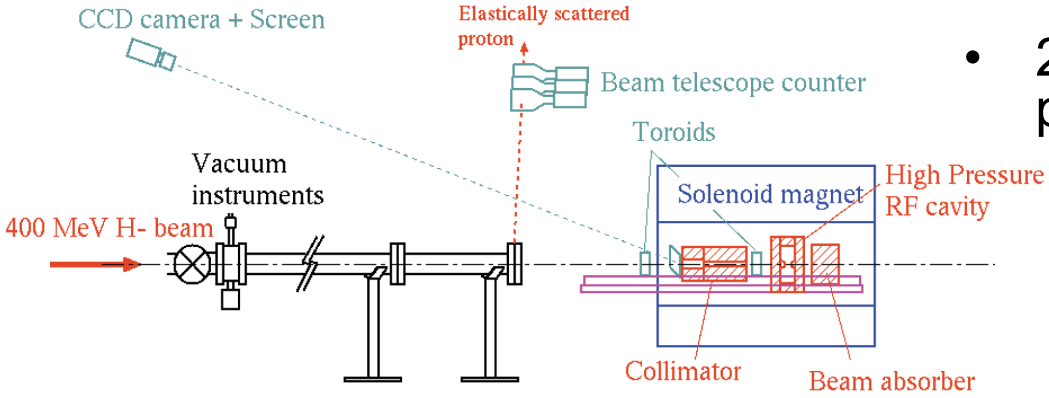




Pressurized RF
805-MHz HPRF Cavity (Muons Inc)

- HPRF concept previously tested at the MTA (Hanlet et al., EPAC06)
  - Dense H_2 gas buffers dark current while serving as cooling medium
  - Allows gradients up to the surface breakdown limit with no B-field effect
  - H_2 supports 1 MV/m per atm
- Response to high-intensity beam
  - Electron-ion pairs produced by beam
  - Beam-induced plasma loads the cavity
  - Mitigate with electronegative dopant gas

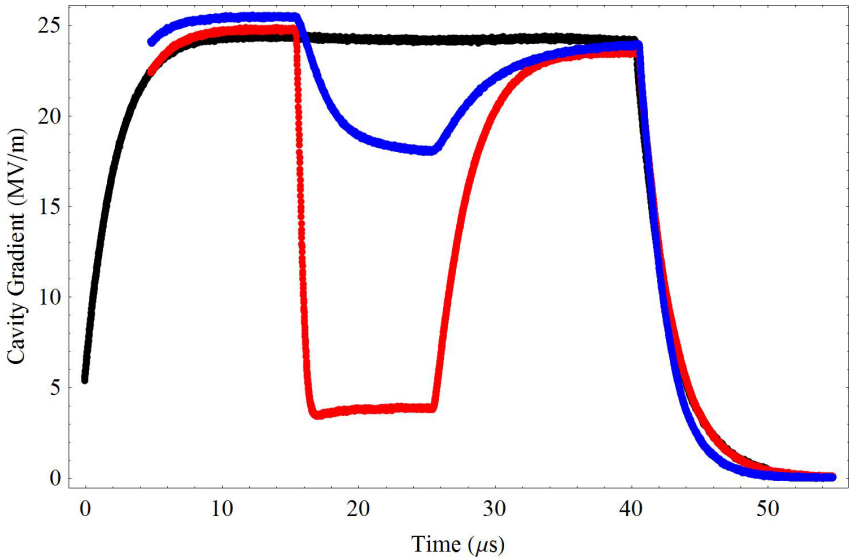




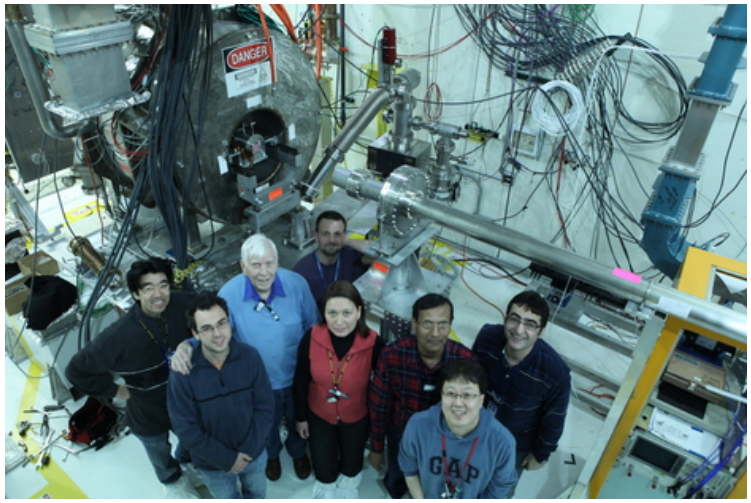
- 2 beam tests performed to evaluate plasma dynamics in the cavity
  - Fermilab Linac beam (400-MeV p)
  - dE/dx per p similar to 100-MeV/c μ
  - ~10^9 protons per bunch

Fermilab 805-MHz HPRF Cavity Beam Test

- Wide range of parameters
  - 10^{10}-3x10^{11} ppp, 0-50 MV/m
  - 300-1520 psi H2, B=0 and 3T
  - Electronegative Dopant Studies: SF6 & dry air effect vs. concentration
  - Ion Mobility Studies: He+air, N2+air, D2
- Publication to be submitted this week
  - Quantitative theory validated by measurement of energy in H2/ D2+dopant (B. Freemire thesis)
  - Electronegative dopants turn mobile ionization electrons into heavy ions, reducing RF losses by large factor
- Results extrapolate well to Neutrino Factory operation and a range of Muon Collider beam parameters
  - Plasma loading < beam loading
  - Bunch intensity limits being evaluated

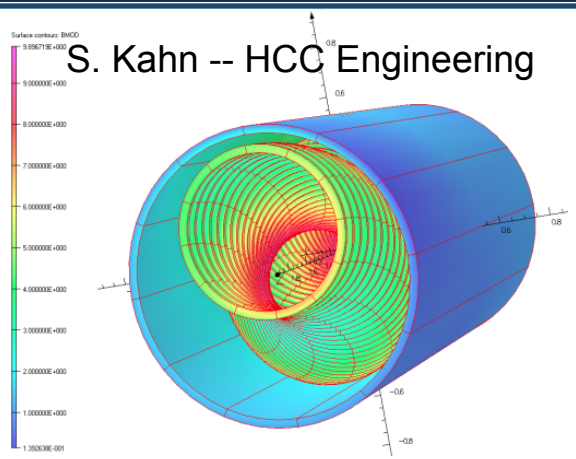


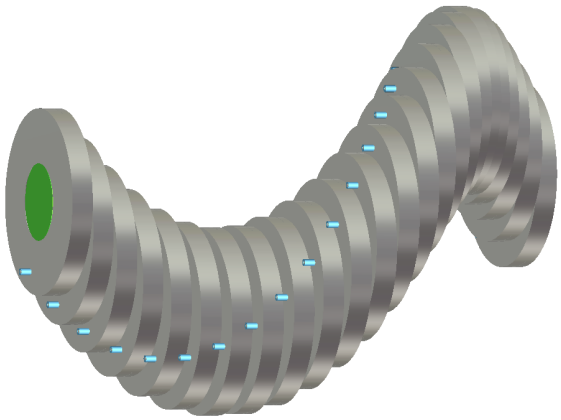
1470psi H2 beam 1% dry air

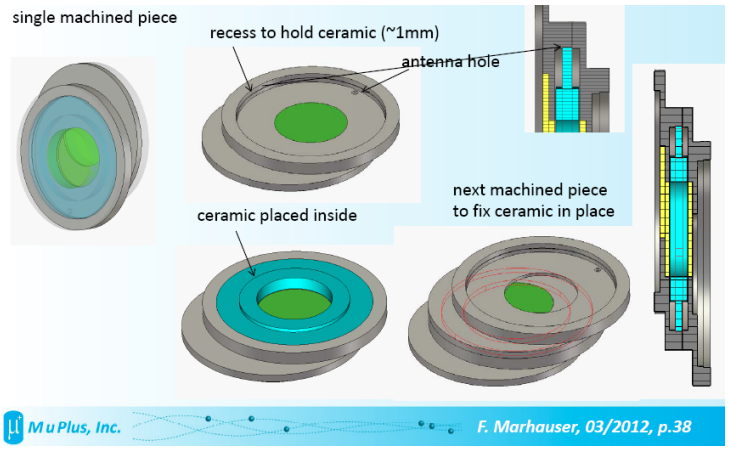


Fermilab 805-MHz Dielectric-loaded HPRF

S. Kahn -- HCC Engineering

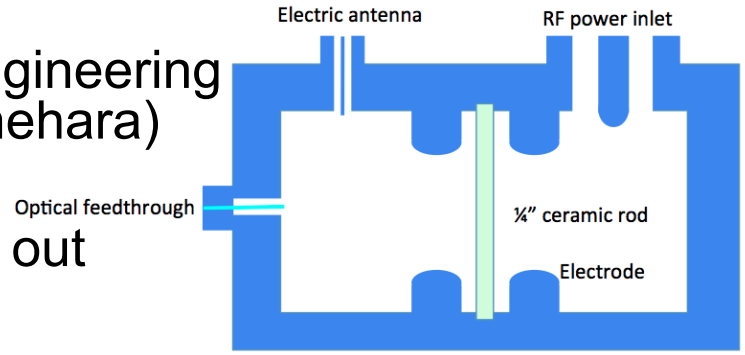


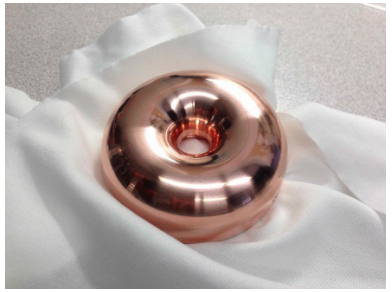




- Magnet apertures in HCC with RF inside helical solenoids lead to large fields on conductors
- Dielectric loading to shrink RF cavities
- High-pressure gas to suppress dielectric surface breakdown

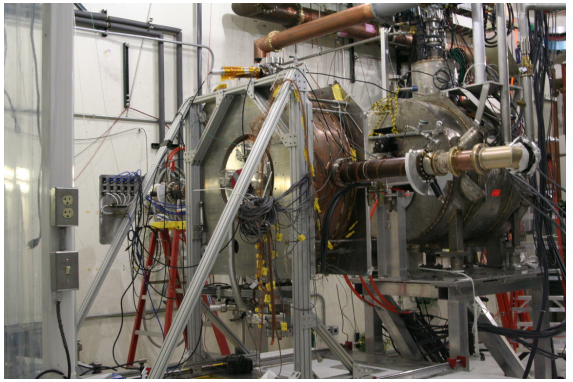
- Muons Inc. grant for HCC engineering design (G. Flanagan, K. Yonehara)
- Hardware in hand
- Initial test with Al2O3 carried out

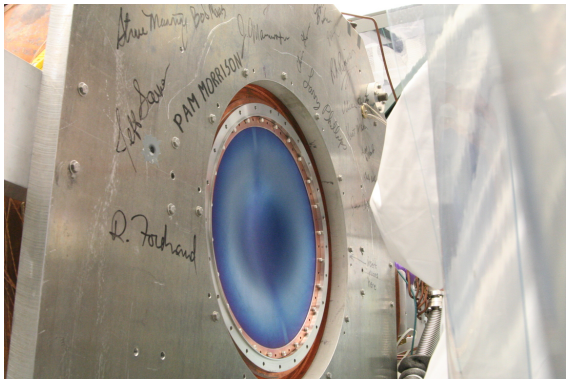


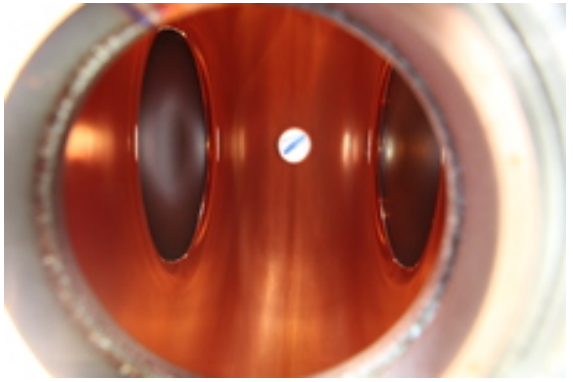


201-MHz Program (Surface treatment, NF channel, MICE)

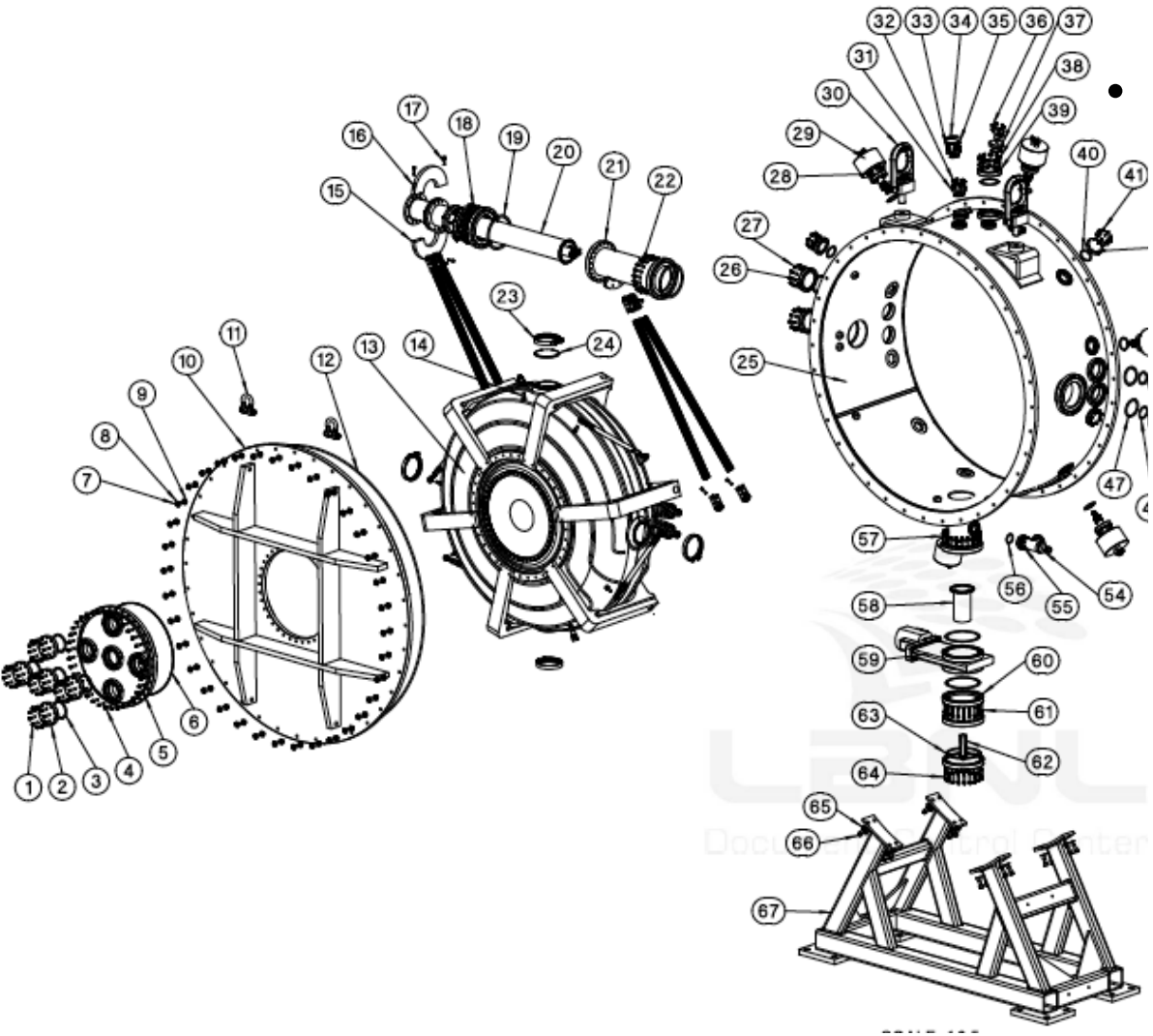
- 201-MHz MICE prototype cavity with SRF-like surface treatment (EP, HP rinse)
  - Conditioned to design gradient quickly
  - Demonstrated operation with large curved Be windows
  - Somewhat reduced performance in fringe field of solenoid
  - No surface damage seen on cavity interior
  - Some evidence for sparking in the coupler
    - Multi-pacting studied
    - Design now modified
    - Also looking into TiN coating
  - Radiation output measured (MICE detector backgrounds)
- Future
  - Install/operate single-cavity vessel
  - Large diameter magnet (coupling coil) needed for field configuration closer to MICE/cooling channel



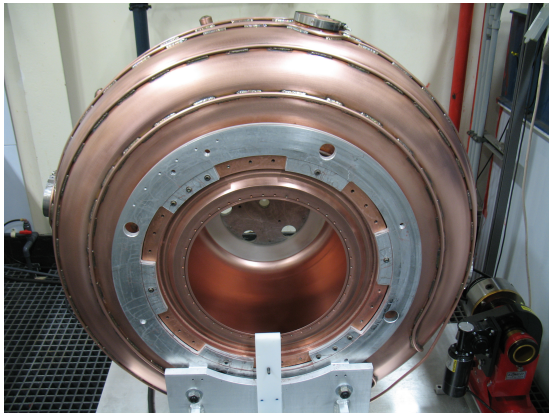




201-MHz Single-Cavity Module

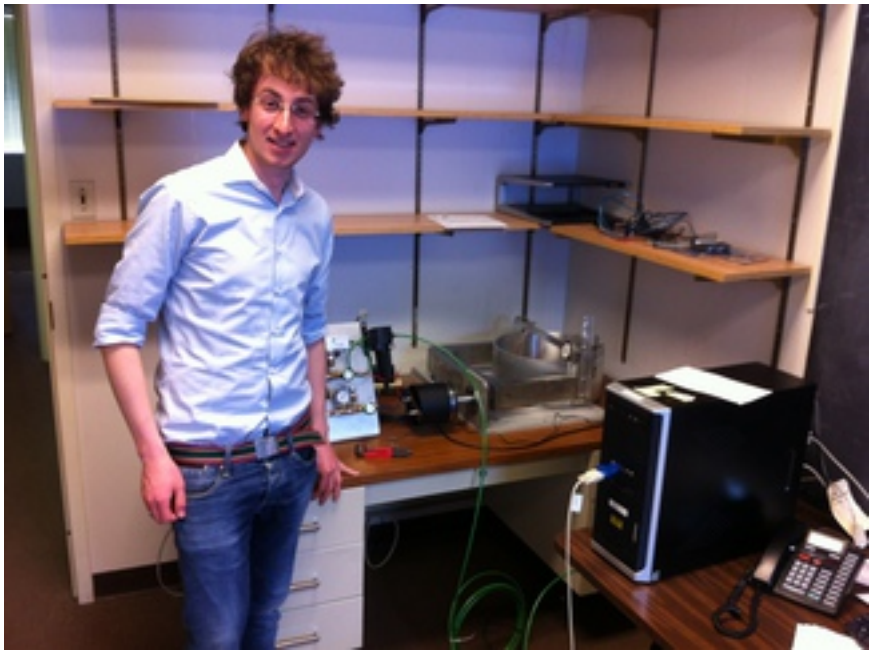


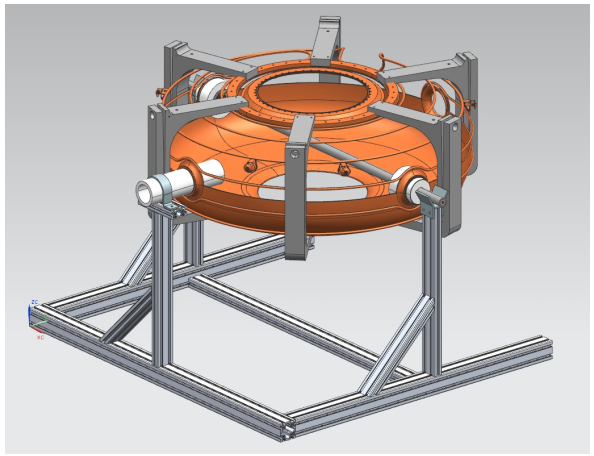
- MICE cavity in vacuum vessel for MTA test
- Components
  - 1st MICE cavity EP'ed at LBNL
  - Vacuum vessel built at Keller Technology
  - Be windows in hand
  - Actuators built at LBNL
  - Tuner forks built at FNAL
  - Fabrication of new couplers started at LBNL

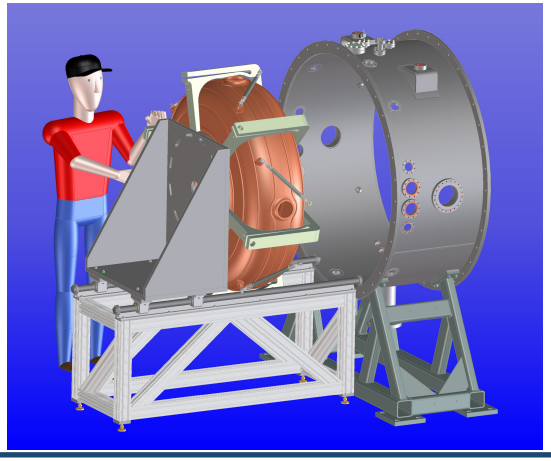


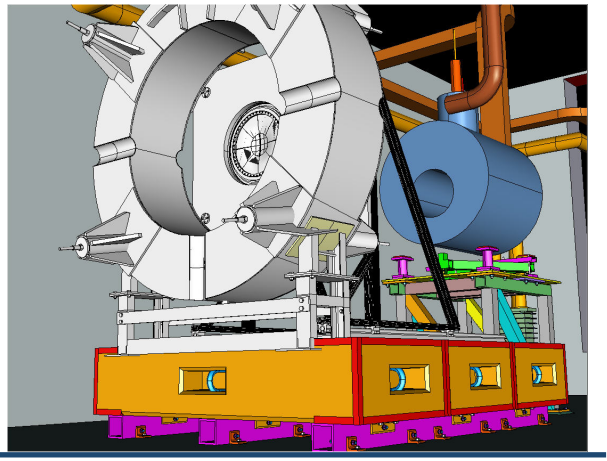
201-MHz Single-Cavity Module

- Assembly/integration
  - Cavity and vessel at Lab-6
  - Clean room prepared
  - Assembly fixtures built
  - Tuner control bench tested
  - Plan in place for handling and transport
- Expect operation Fall 2013
  - Option for beam test
- Ultimately will be tested with the first Coupling Coil Magnet
  - Requires 6-month MTA shutdown



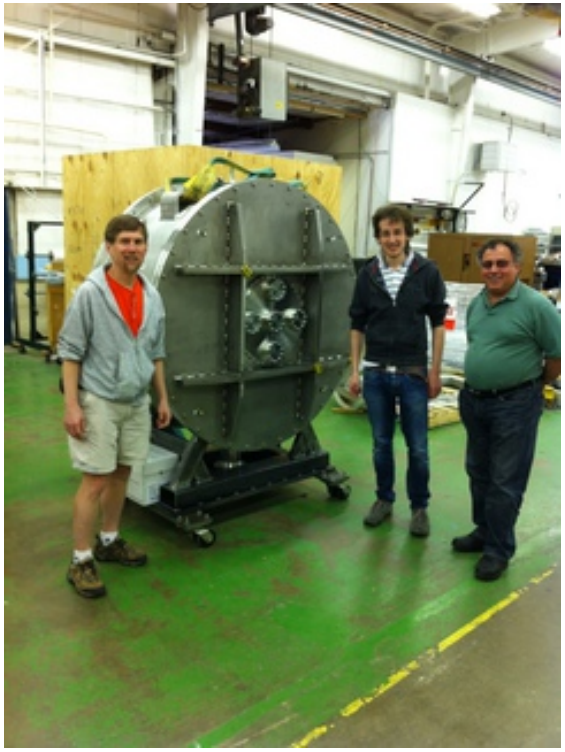






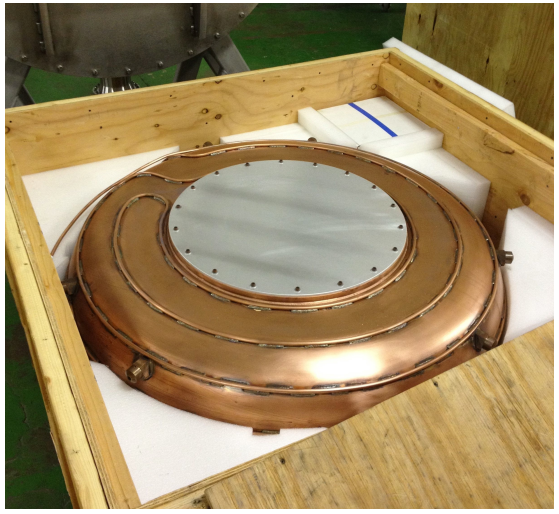
Components in Lab-6

Vacuum vessel on transport stand



Tuner installation fixture (horizontal stand)

Tuner forks



Cavity

Outlook

- Experimental program
  - HPRF beam tests successfully concluded
    - Looks promising for Neutrino Factory and Muon Collider application
    - Dielectric loading tests started
  - Vacuum cavity R&D bearing fruit
    - 20+ MV/m @ 3T demonstrated in Cu pillbox (all-season cavity), follow-on testing underway
    - Alternative window geometry to be explored
    - New modular cavity in fabrication for detailed systematic studies (Cu/Be walls, gradient vs B)
    - Beam tests will be included in experimental program
    - 201-MHz single-cavity module (MICE) tests
      - Tests with Coupling Coil Magnet will follow when magnet prototype ready
- Infrastructure upgrades (beamline, RF, magnets)
- ***R&D program now pointing the way to RF solutions for ionization cooling channels!***

Recent publications
http://mice.iit.edu/mta/papers.html

- Measurement of transmission efficiency for 400 MeV proton beam through collimator at Fermilab MuCool Test Area using Chromox-6 scintillation screen, M. R. Jana *et al.*, Rev. Sci. Instrum. 84, 063301 (2013)
- Analysis of Breakdown Damage in an 805 MHz Pillbox Cavity for Muon Ionization Cooling R&D, D. Bowring *et al.*, IPAC13
- A Modular Cavity for Muon Ionization Cooling R&D, D. Bowring *et al.*, IPAC13
- Transient Beam Loading Effects in Gas-filled RF Cavities for a Muon Collider,M. Chung *et al.*, IPAC13
- Beam Induced Plasma Dynamics in a High Pressure Gas-Filled RF Test Cell for use in a Muon Cooling Channel, B. Freemire *et al.*, IPAC13
- Multipacting Simulation of the MICE 201 MHz RF Cavity,T. Luo *et al.*, IPAC13
- High Power Tests of Alumina in High Pressure RF Cavities for Muon Ionization Cooling Channel, L. Nash *et al.*, IPAC13
- The RF System for the MICE Experiment, K. Ronald *et al.*, IPAC13
- RF Cavity Spark Localization Using Acoustic Measurement, P. Snopok *et al.*, IPAC13
- Simulation of Beam-induced Gas Plasma in High Gradient RF Field for Muon Colliders, K. Yonehara *et al.*, IPAC13
- Summary of Dense Hydrogen Gas Filled RF Cavity Tests for Muon Acceleration, K. Yonehara *et al.*, IPAC13
- Can surface cracks and unipolar arcs explain breakdown and gradient limits?, Z. Insepov and J. Norem, J. Vac. Sci. Technol. A 31, 011302 (2013)
- Sheath parameters for non-Debye plasmas: Simulations and arc damage, I. V. Morozov *et al.*, Phys. Rev. ST Accel. Beams 15, 053501 (2012)
- Progress on a Cavity with Beryllium Walls for Muon Ionization Cooling Channel R&D, D. Bowring *et al.*, IPAC12 proceedings
- Electron Recombination in a Dense Hydrogen Plasma, B. Freemire *et al.*, IPAC12 proceedings
- Study of Electronegative Gas Effect in Beam-Induced Plasma, B. Freemire *et al.*, IPAC12 proceedings
- Beam Profile Measurement in MTA Beam Line for High Pressure RF Cavity Beam Test, M. Jana *et al.*, IPAC12 proceedings
- Conditioning and Future Plans for a Multi-purpose 805 MHz Pillbox Cavity for Muon Acceleration, G. Kazakevich *et al.*, IPAC12 proceedings
- Improved RF Design for an 805 MHz Pillbox Cavity for the US MuCool Program, Z. Li *et al.*, IPAC12 proceedings
- Progress on the MICE 201 MHz RF Cavity at LBNL,T. Luo *et al.*, IPAC12 proceedings
- Progress in Modeling Arcs, J. Norem *et al.*, IPAC12 proceedings
- Kinetic Modeling of RF Breakdown in High-Pressure Gas-filled Cavities, D. Rose *et al.*, IPAC12 proceedings
- Beam Tests of a High Pressure Gas-Filled Cavity for a Muon Collider, T. Schwarz *et al.*, IPAC12 proceedings
- Influence of Intense Beam in High Pressure Hydrogen Gas Filled RF Cavities, K. Yonehara *et al.*, IPAC12 proceedings
- An Automated Conditioning System for the MUCOOL Experiments at Fermilab, A. Kurup, IPAC11 proceedings
- High Pressure RF Cavity Test at Fermilab, B. T. Freemire *et al.*, PAC11 proceedings
- Multi-purpose 805 MHz Pillbox RF Cavity for Muon Acceleration Studies G.M. Kazakevich *et al.*, PAC11 proceedings
- Vacuum Arcs and Gradient Limits, J. Norem *et al.*, PAC11 proceedings
- Enhancement of RF Breakdown Threshold of Microwave Cavities by Magnetic Insulation, D. Stratakis *et al.*, PAC11 proceedings
- Beam Test of a High Pressure Cavity for a Muon Collider, M. Chung *et al.*, IPAC10 proceedings, p3494
- Beam-induced Electron Loading Effects in High Pressure Cavities for a Muon Collider, M. Chung *et al.*, IPAC10 proceedings, p3497
- The US Muon Accelerator Program, Y. Torun *et al.*, IPAC10 proceedings, p3491
- The MuCool Test Area and RF Program, Y. Torun *et al.*, IPAC10 proceedings, p3780
- Rectangular Box Cavity Tests in Magnetic Field for Muon Cooling, Y. Torun *et al.*, IPAC10 proceedings, p3795
- Study of Electron Swarm in High Pressure Hydrogen Gas Filled RF Cavities, K. Yonehara *et al.*, IPAC10 proceedings, p3503

Recent student projects
http://mice.iit.edu/mta/students/

- Luca Somaschini (Pisa) – 201-MHz tuner system and instrumentation
- Logan Rowe (Kettering) – 201-MHz module assembly
- John Sobolewski (Marquette) – adapters for inspection/microscopy
- Jared Gaynier (Kettering) – circulator & CC installation
- Lisa Nash (U. Chicago) – dielectric loaded HPRF
- Adam Sibley (Trinity) – HPRF breakdown study
- Oleg Lysenko (U. Chicago) – HPRF beam test
- Jessica Cenni (Pisa) – dielectric loaded cavity
- Tom Mclaughlin (Valparaiso) – magnet mapping, circulator installation
- Ivan Orlov (Moscow State) – HPRF beam test simulation
- Raul Campos (NC State) – beamline magnet support
- Peter Lane (IIT) – acoustic sensors for RF breakdown
- Timofey Zolkin (U. Chicago) – dark current instrumentation
- Giulia Collura (Torino) – HPRF beam test
- Ben Freemire (IIT) – HPRF beam test (Ph. D.), other tests
- Last Feremenga (U. Chicago) – magnetic field mapping
- Anastasia Belozertseva (U. Chicago) – magnet mapping